NUCLEON SPIN PUZZLE: TEN YEARS LATER...

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This is a brief survey of the present state of ideas concerning the parton content of the nucleon spin after their ten-years evolution since the discovery of the EMC.

In 1974 an article [1] appeared in the Physical Review in which J. Ellis and R. Jaffe deduced some predictions (sum rules) concerning structure functions of polarized lepton-nucleon deeply inelastic scattering.

The predictions were based on some apparently natural assumptions like the negligible rôle of strange quarks in the formation of the nucleon spin. The result did not cause a noticeable agiotage. The general attention was focused then on another problems.

Meanwhile some other important works were published among which one has to mention papers [2] (calculation of the "polarized" anomalous dimension whose lowest order is $0(\alpha_s^2)$ in contrast to usual $0(\alpha_s)$ for "unpolarized" anomalous dimensions. Later this anomalous dimension was calculated to three loops [3].) and [4] (establishing a relation of the problem to the chiral anomaly and discussion of the rôle of the gluon helicity).

A crash of thunder happened only in 1988 when the results of the European Muon Collaboration were published [5]. The three-standard deviation of the Ellis-Jaffe prediction from the data produced a great impression and caused a flow of theoretical publications as well as new experimental measurements both at CERN and SLAC.

A "simple minded" interpretation of the EMC data as an evidence that the nucleon spin is not formed mainly by valence quarks was rejected by some authors as absolutely counter intuitive, highly unnatural and, thus, appealing for a more sophisticated consideration, which could reconcile the data and "natural" ideas on composition of the nucleon spin [6]. Nonetheless some other theorists accepted this interpretation arguing that at rather small distances (corresponding to $Q^2_{EMC} \simeq 10\text{GeV}^2$) constituent quark picture ceases to be relevant and the total nucleon spin is "smeared" over a large number of "resolved" quarks, antiquarks and gluons [7]. They also indicated that the new definition of the spin content of the proton has severe problems with gauge invariance.

There was one more idea [8] stating that the EMC result has nothing to do with the proton spin at all, and should be considered as a manifestation of some

general topological properties of gauge fields. In the broad sense Ref. [9] can be also attributed to this trend.

Roughly these three “schools” remain to be the main directions of theoretical interpretation of the puzzle, discovered by the EMC and confirmed many times at CERN, SLAC and DESY (HERMES) up to present time.

We use the term “puzzle” instead of often used “crisis” or “problem” because the EMC result, formally speaking, does not contradict to the first principles of the official theory of strong interactions (i.e. QCD). One should note also that at present nobody is able to calculate measurable polarized (as well as unpolarized) structure functions, so, in general one has nothing from the theory to be verified or falsified.

We deal, instead, with some vague symbiosis of QCD and extra assumptions which can (or cannot) be considered as “natural”, “plausible” etc.

Nonetheless such a situation seems to be inevitable because one will hardly be an eye-witness of a beautiful day when it will be possible to deduce rigorously all or many enough experimentally testable predictions from the theory (QCD).

The main ideas and tools of the three above-mentioned approaches were described and discussed in literature and oral talks so many times that we limit ourselves to their general outline.

The first school based its interpretation of the spin puzzle on the chiral anomaly, inherent to the singlet axial current and called for the resque of “common sense”. “There is no longer a spin crisis” [10] was a proud conclusion made as early as in 1988 by some proponents of this approach.

In fact the problem was shifted from the quark part of the proton spin to its gluon (both spin and orbital) part, the latter being as ill understood as the quark one. Provided with the “natural” value of the quark contribution (i.e. in full accordance with the quark constituent model where the nucleon spin is nearly defined by the quark spin) the adepts of the school under discussion raised the problem of “gluonic” spin contribution both in the sense of its proper formal definition and calculation and independent experimental measurement.

The seconds school, as was already said, accepted readily the EMC data as an exciting evidence that deeply inside the nucleon things look different from what one could envisage from an earlier large-distance experience.

There were quite interesting disputes and new proposals (see e.g. [11]), which independently of the very subject of discussion have played very useful rôle attracting attention of theorists to basic notions of theory and motivating new experiments.

At the moment no unique solution of the puzzle in question is accepted by the “public opinion” (I should not like to estimate percentage).

But I would like to treat the problem from a different point of view. The matter is that all speculations on the internal content of the nucleon (i.e. global characteristics such as energy-momentum, spin etc.) deal with the formal expressions physical interpretation of which depends on some "suitable" convention.

For instance, parton densities in the nucleon are defined by some composite operators averaged over the 1-nucleon state. These operators depend on some arbitrary mass scale (renormalization scale), on one another arbitrary convention (renormalization scheme). The interpretation of the matrix elements of these operators as parton densities depends crucially on the renormalization scheme and, what is more serious, on the choice of a gauge of the gluon field. Such dependence can be assimilated to frame dependence in special relativity. This means that parton interpretation of the matrix elements of composite operators has no direct objective meaning. In principle one is able to extract these matrix elements from the data and check directly the QCD predictions without partonic interpretation which is akin to mechanical models of electromagnetic phenomena used in the XIX century.

Somewhat similar approach to the EMC spin effect was undertaken in Ref.[12], where the value of the integral of g_1 was related to general properties of the gluon field configuration expressed in terms of the so-called "topological susceptibility". General character of the latter quantity led the authors of this (somewhat formal) school to the conclusion about target independence of the EMC spin effect. This prediction is waiting for the experimental check. But once again its possible failure will not threat the basics of QCD because the inference is based on some extra assumptions wich may or may not hold in QCD.

Returning to the problem of the parton content of the nucleon spin it worth noting that disputes on what definition of the "quark part" of the nucleon spin is correct cannot be resolved with new experimental data. Partly because the full x-interval $[0, 1]$ will never be covered leaving the room for doubts in non-explored regions of x (see e.g. [13]).

But mainly because the "problem" being dependent on various definitions and arbitrary conventions lies in another, metaphysical plane.

This conclusion can seem quite discouraging and too pessimistic. But on the other hand this should promote our thoughts about such basic notions as "constituents", conventionality, etc. and their relevance to the interpretation of the data in these terms. In this sense ten years have passed not for nothing.

At any rate, I believe, it will be interesting for you to know laconic characterisations of the present situation made by the two "culprits". "Pregnant!" (J. Ellis) [14]; "Delightful!"(R. Jaffe) [15]. I am not pretty sure what they meant, each of them, but taken together these words are not contradictory and may promise a

birth of new, exciting puzzles.

For, I think, Louis de Broglie was prophetically right when he wrote as early as in 1955 [16]: "... le spin est certainement un des éléments les plus essentiels, peut-être même le plus essentiel, de l'existence des particules".

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